GRAIL Gravity Field Determination Using the Celestial Mechanics Approach – First Results

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Celestial Mechanics Approach (CMA)

Celestial Mechanics Approach:
Gravity field recovery is rigorously treated as an extended orbit determination problem, i.e., all available measurements contribute to one and the same set of parameters

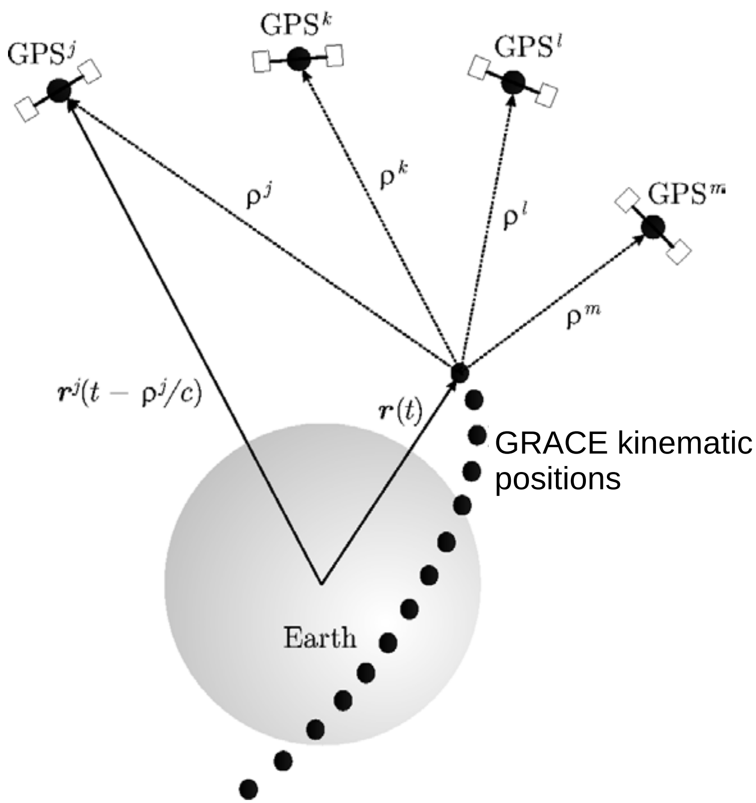
The approach is flexible with respect to

- **Parameter set-up**
- **Normal equation modifications**

→ Generation of ensembles of solutions

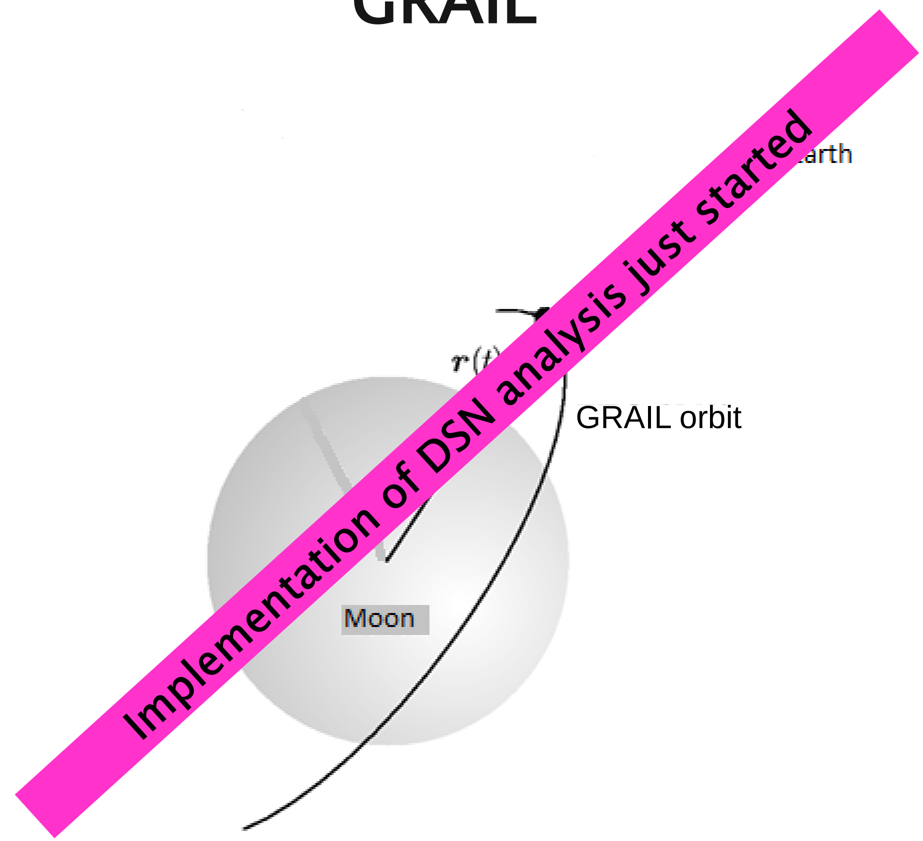
Celestial Mechanics Approach (CMA)

GRACE



The GRACE satellites may be geo-located with cm-accuracy at any time, e.g., by a kinematic precise point positioning.

GRAIL

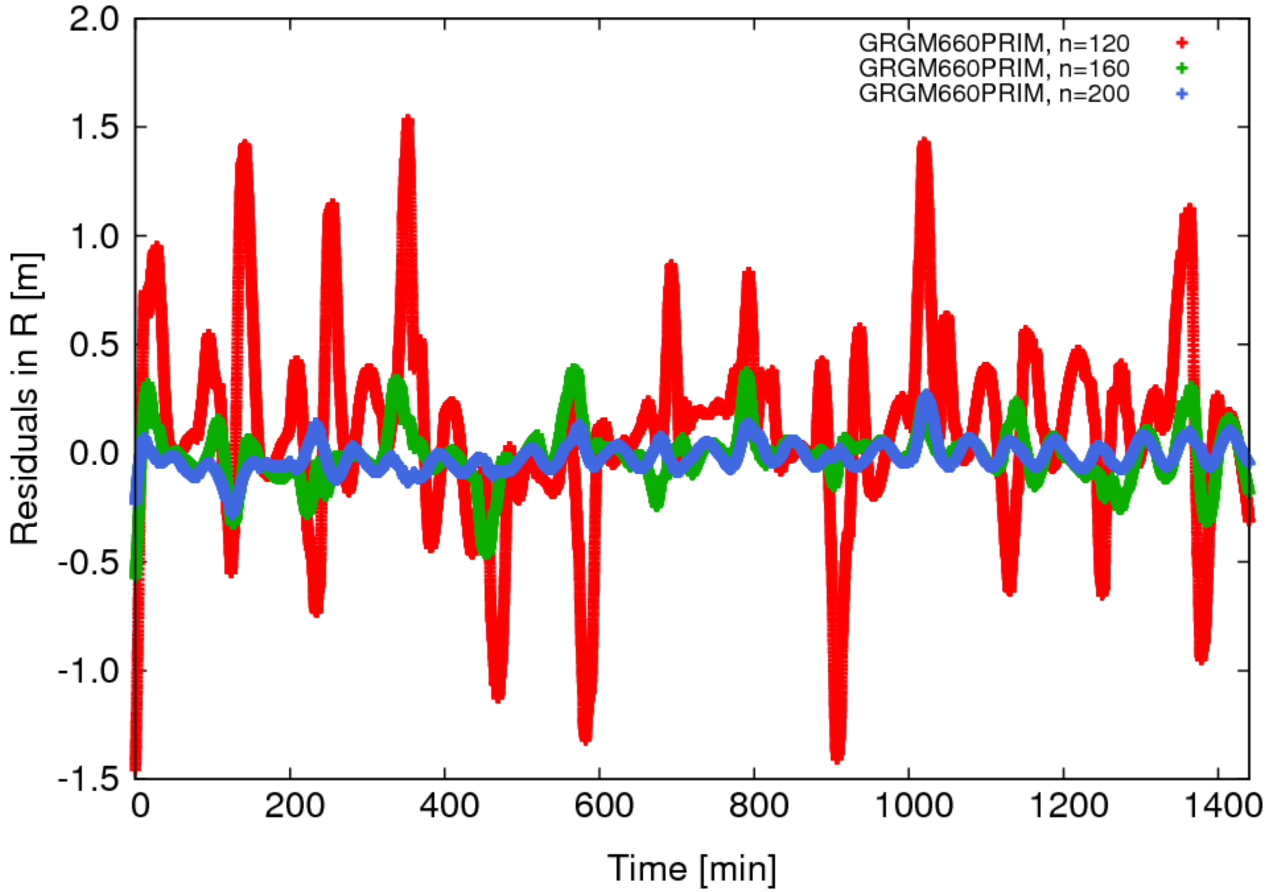


The orbits of the GRAIL satellites may be constrained by Doppler measurements.

CMA – Current Status

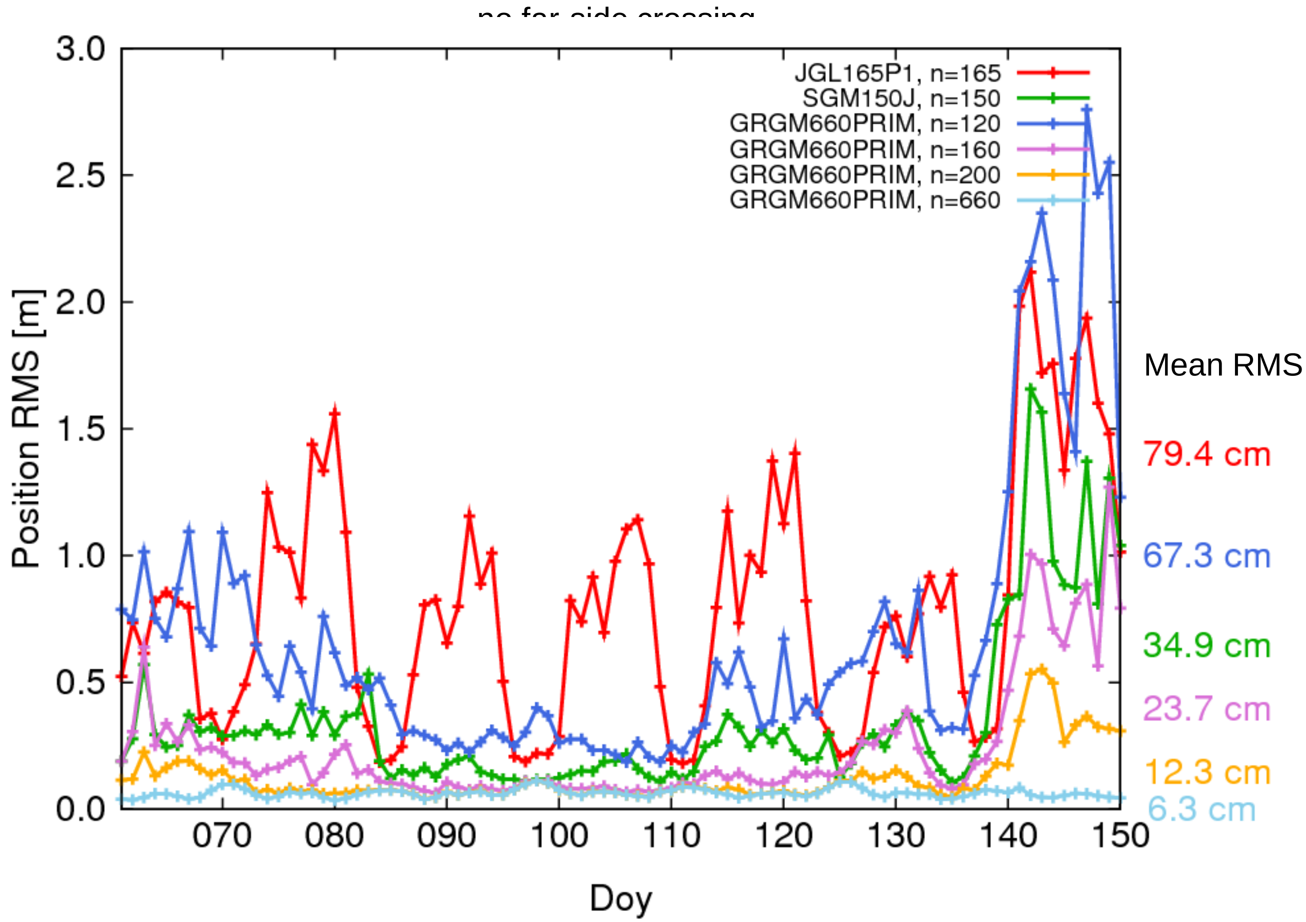
Static field	• SH expansion up to d/o 120, 160, 200
Data	• GNI1B positions, DOYs 062–150, (243–333) • KBR1B range-rates, “ , “
Orbits	• Initial conditions every 24h • Pulses every 40 min
K-band	• Time bias every 24h
A priori	• JGL165P1, SGM150J, GRGM660PRIM
RPR	• No parametric model implemented yet
Background	• Reference frame trafo (DE-405) • 3rd body-perturbations • No tide model implemented yet
Weighting	• Position : K-Band = 1 : 10^8

GNI1B Pseudo-Observation Fits



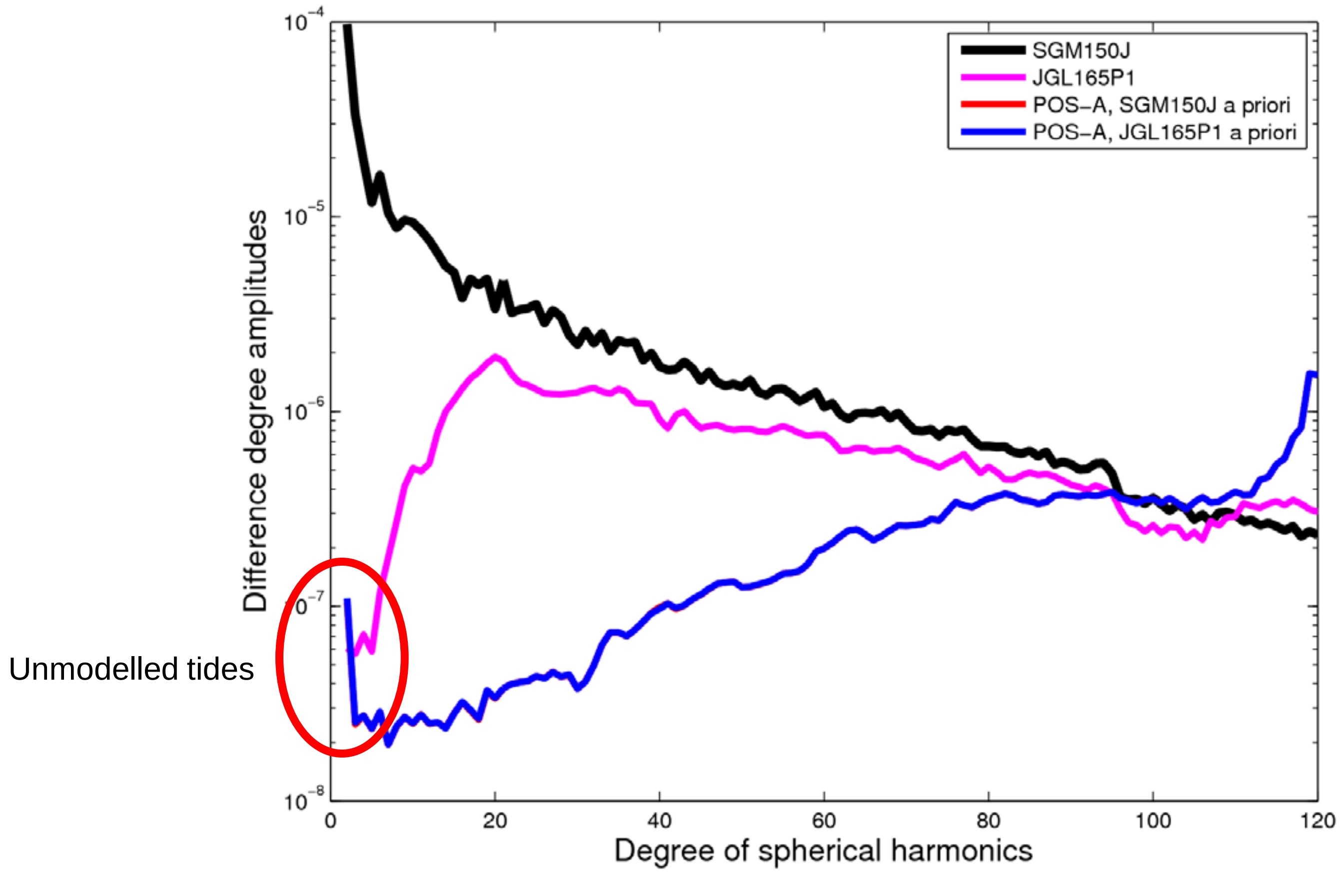
Radial position residuals for GRAIL-A from an orbit determination using position pseudo-observations. Larger residuals on the far-side are clearly visible for the “old” gravity field models JGL165P1 and SGM150J. Significantly improved representation when using the GRAIL gravity field models up to d/o 120, 160, 200 (no far-side effect).

GNI1B Pseudo-Observation Fits



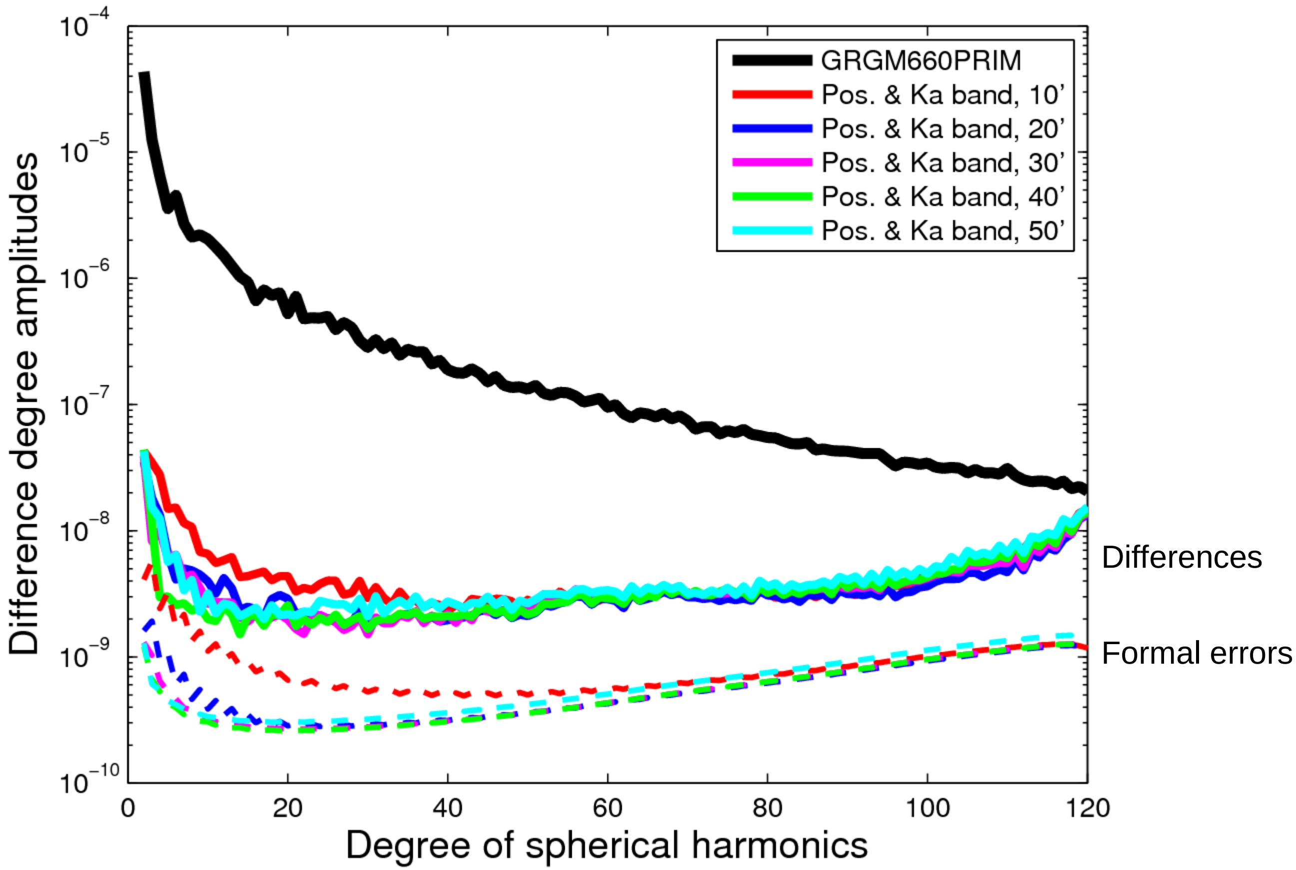
Daily RMS values for GRAIL-A from an orbit determination using position pseudo-observations. Slightly worse fits are still obtained for the beginning and end of the mission when using the GRGM660PRIM just to d/o 200.

Position Solutions – Linearization Issues?



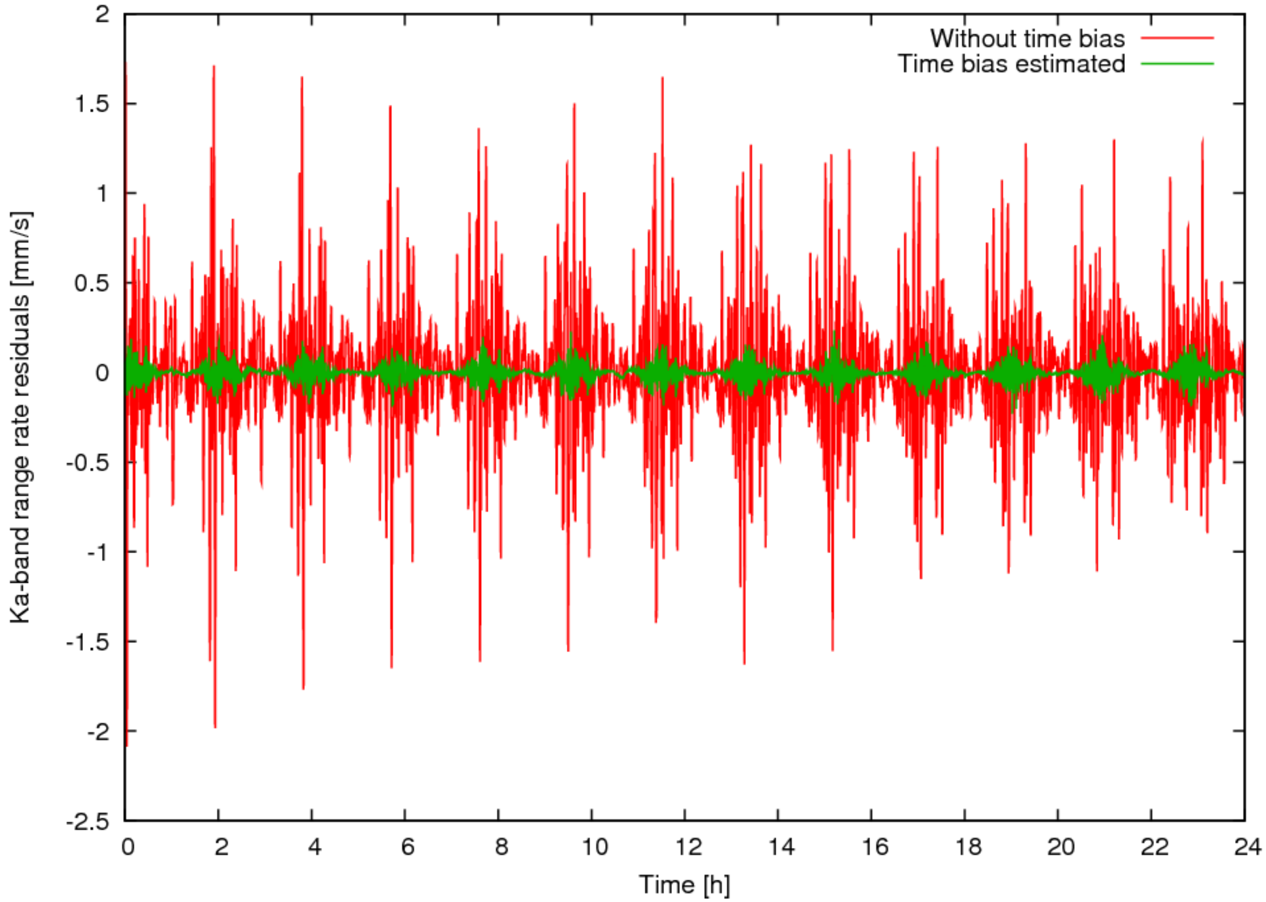
Differences between the JGL165P1 and the **SGM150J** a priori gravity field model are huge. Independently of the used a priori gravity model, the CMA solutions based on GRAIL-A position pseudo-observations agree equally well with SGM150J within one iteration.

Combined Solutions – Impact of Pulses



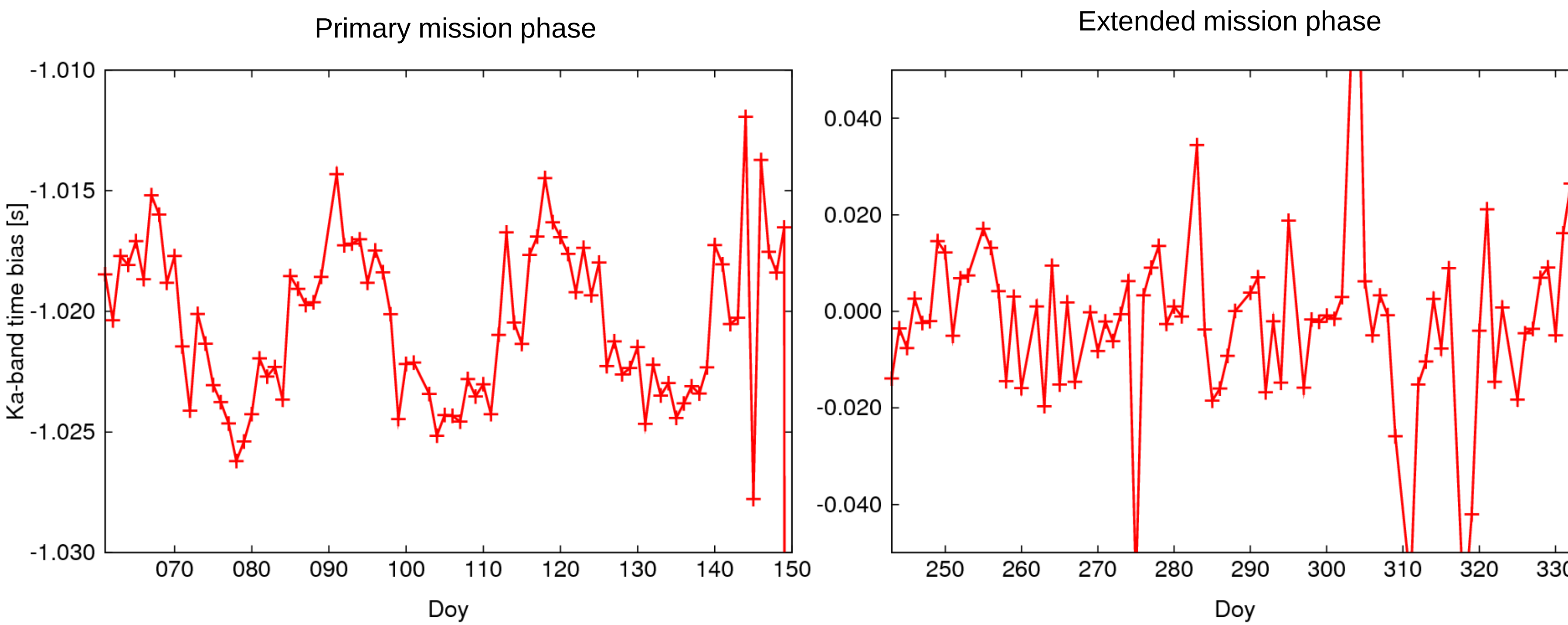
Pulses are set up to compensate for not yet explicitly modelled forces, e.g., radiation pressure. The “optimal” pulse spacing of 40 min for solutions up to d/o 120 follows from both the formal errors of the CMA solutions and the differences wrt **GRGM660PRIM**.

KBR1B Range-Rate Observation Fits



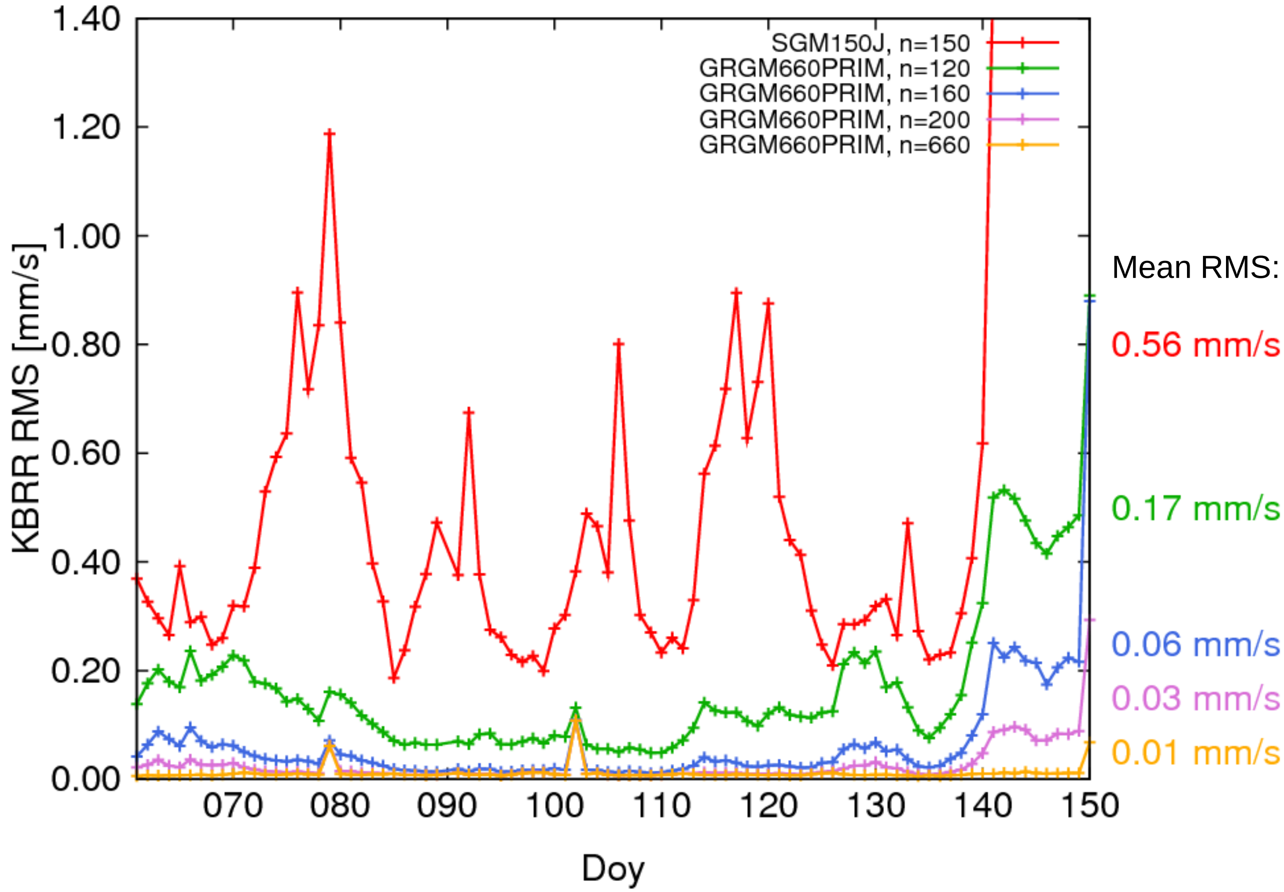
K-Band residuals when using the GRGM660PRIM gravity field model up to d/o 160. Significant reductions are achieved by estimating one K-Band time-tag offset per daily arc.

KBR1B Time Biases



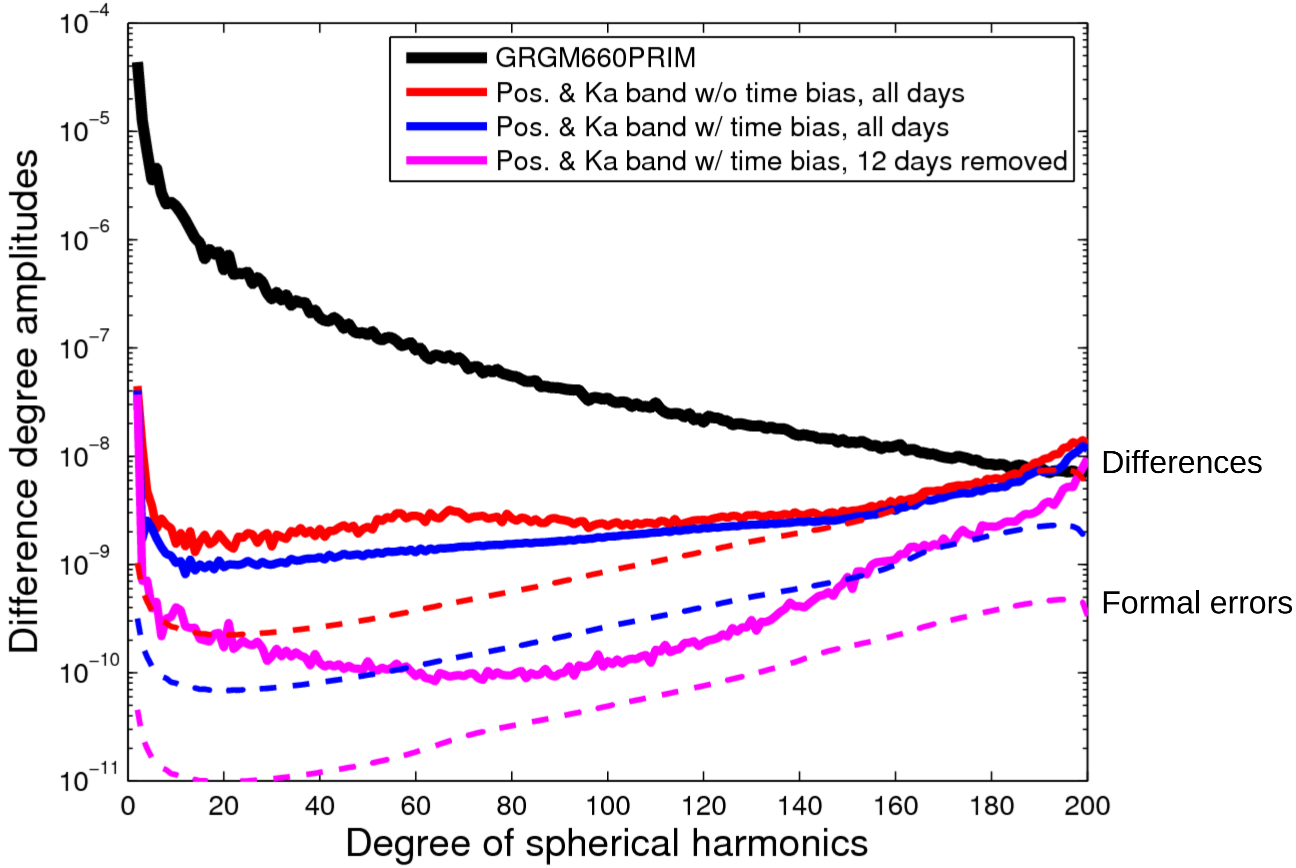
A significantly different behavior of the time biases is observed for the primary mission phase (-1.026 sec) and the extended mission phase (-0.002 sec).

KBR1B Range-Rate Observation Fits



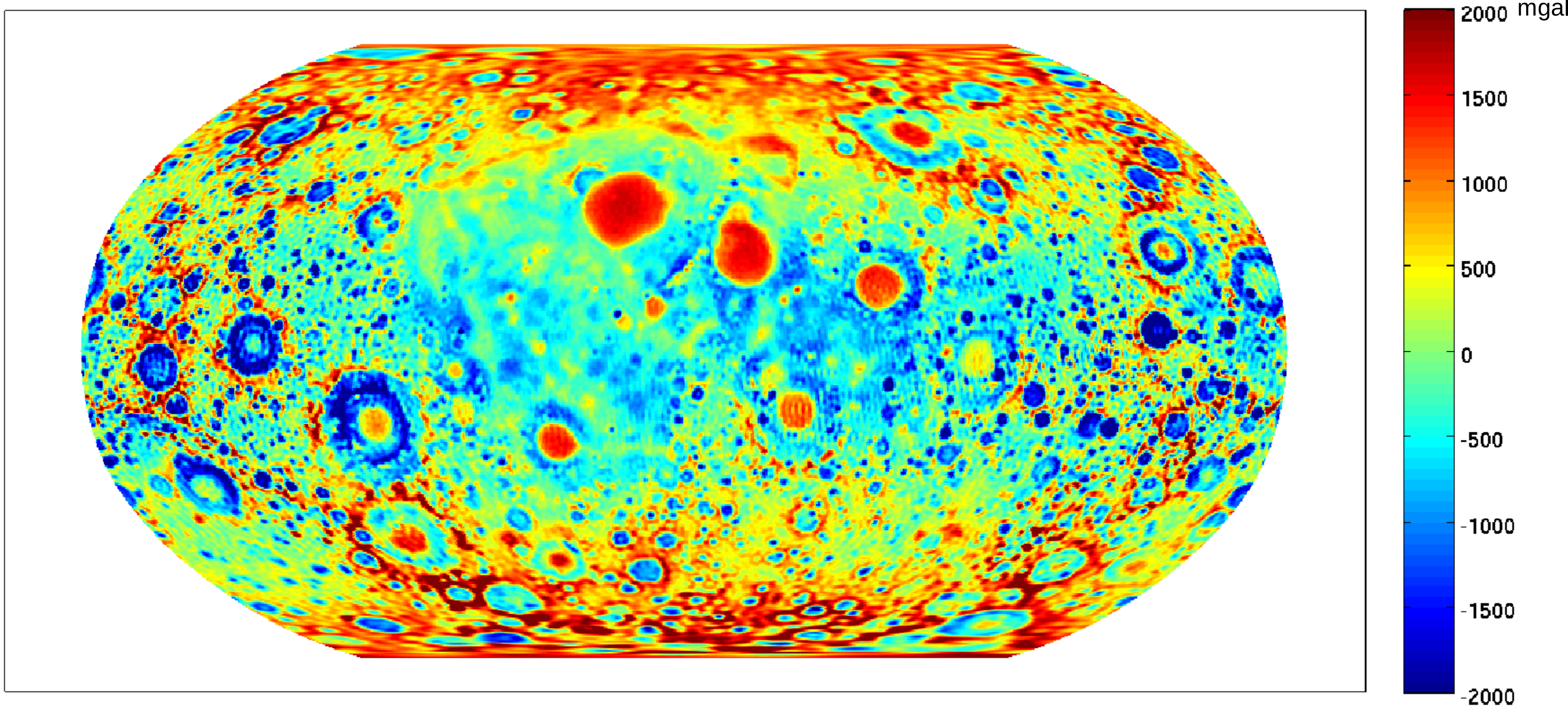
Daily K-Band RMS values from a combined orbit determination using position pseudo-observations and K-Band range-rate data with a weighting ratio of 1:10^8. Obviously there is still a long way to go to reach the K-Band residual level …

First Combined Solutions up to d/o 200



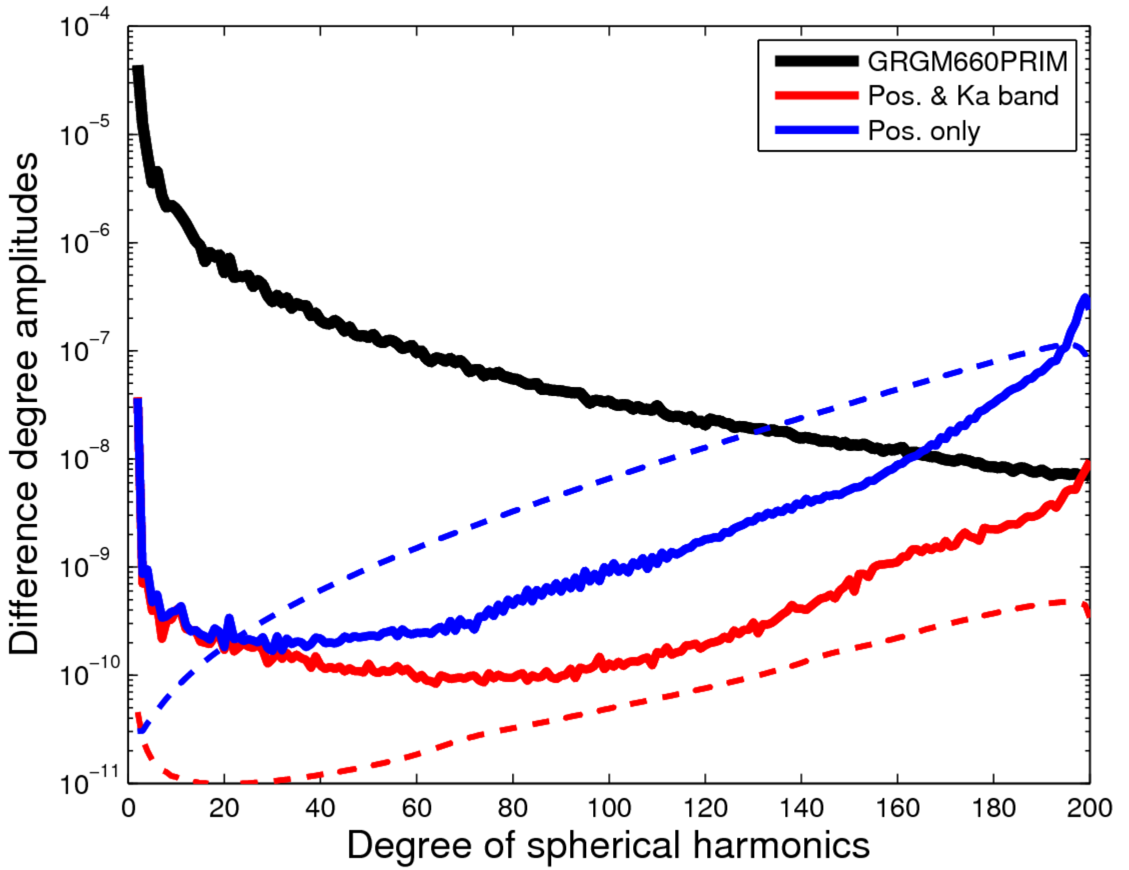
Co-estimation of K-Band time-tag offsets seems to be important when processing the data of the primary mission phase. Further improvements are achieved when skipping a few problematic days (12 days show larger residuals, needs to be further investigated).

First Combined Solutions up to d/o 200



Gravity anomalies from the combined gravity field solutions up to n_{max} = 160 and 200, resp. For the higher resolution solution some artifacts (stripes) are visible ...

First Combined Solutions up to d/o 200



The solution is currently dominated up to d/o 30 by the GNI1B position pseudo-observations and represents thus not yet a fully independent recovery. According to the formal errors this should change when further exploiting the KBR1B data, but the implementation of DSN data analysis is a **must** to obtain fully independent results also for the long wavelengths.

Conclusions

- Availability of GNI1B data allowed for an “easy start” to extend the CMA to GRAIL gravity field recovery
- Empirical orbit parameters allowed to generate first “Bernese” lunar gravity field solutions without using sophisticated background models
  - Efforts are needed to improve the background models
- Basic understanding of the observables is achieved
  - Large effort is still needed to “see” the KBR residual level
- Low degrees are biased towards GRGM660PRIM due to the use of GNI1B data as pseudo-observation
  - DSN data analysis capability is a must (efforts have started)

=> Still a long way to go, but the prospect to provide an independent solution might justify the effort